Attorney Docket No. SP01-146
Filing Date: 6/1/01

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METHODS AND APPARATUS FOR FORMING AND CONTROLLING THE DIAMETER OF DRAWN OPTICAL GLASS FIBER

Field of the Invention

The present invention relates to methods and apparatus for forming optical glass fiber, and, more particularly, to methods and apparatus for forming and controlling the diameter of drawn optical glass fiber.

Background of the Invention

According to known processes, optical glass fiber may be drawn from a glass preform or blank using a draw furnace. The draw furnace has a chamber that is heated, for example, by induction heating, so that the lower tip of the preform is melted and the optical fiber is drawn from the tip. As the fiber descends from the tip, it is further drawn so that its diameter is progressively reduced. Transients may occur as the molten fiber is drawn so that variations or non-uniformities are created in the fiber. These non-uniformities may negatively affect the properties of the optical fiber, for example, by creating inconsistencies along the length of the fiber. Variations in the fiber diameter may also impact downstream processes, such as fiber coating, resulting in inferior fiber product and/or process stoppage. Hence, improved optical glass fiber diameter control is desirable for process stability, quality control and equipment utilization improvement.

Summary of the Invention

Embodiments of the present invention include an apparatus for forming optical fiber from a glass preform using a forming gas includes a draw furnace having first and second opposed ends. The draw furnace defines an exit opening at the second end and a furnace passage extending between the first and second ends. A control tube extends through the exit opening of the draw furnace. The control tube defines first and second opposed tube openings and a tube passage extending between the first and second tube openings. The control tube includes a first tube section and a second tube section. The first tube opening and the first tube section are disposed in the furnace passage and cooperate with the passage of the draw furnace to form a buffer cavity adjacent the control tube. The second tube opening and the second tube section are disposed downstream of the draw furnace. The tube passage includes an inner diameter. The inner diameter of the tube passage is less than an inner diameter of the furnace passage. The draw furnace and the control tube are adapted such that substantially all of the forming gas enters the furnace passage upstream of the first tube opening and exits the apparatus through the control tube.

According to further embodiments of the present invention, a method for forming an optical fiber includes providing an apparatus. The apparatus includes a draw furnace having first and second opposed ends. The draw furnace defines an exit opening at the second end and a furnace passage extending between the first and second ends. A control tube extends through the exit opening of the draw furnace. The control tube defines first and second tube openings. The control tube includes a first tube section and a second tube section. The first tube opening and the first tube section are disposed in the furnace passage and cooperate with the furnace passage to form a buffer cavity adjacent the control tube. The second tube opening and the second tube section are disposed downstream of the draw furnace. The tube passage includes an inner diameter. The inner diameter of the tube passage is less than an inner diameter of the furnace passage. An optical glass fiber is drawn through the furnace passage and the control tube. During the step of drawing the optical glass fiber, a forming gas is flowed through the furnace passage and the control tube such that substantially all of the forming gas enters the furnace passage upstream of the first tube opening and exits the apparatus through the control tube.

Further features and advantages of the present invention will be appreciated by those of ordinary skill in the art from a reading of the figures and the detailed description of the preferred embodiments which follow, such description being merely illustrative of the present invention.

Brief Description of the Drawings

The accompanying drawing, which is incorporated in and constitutes a part of the specification, illustrates embodiments of the invention and, together with the description, serves to explain principles of the invention.

Figure 1 is a schematic, cross-sectional view of a fiber forming apparatus according to embodiments of the present invention;

Figure 2 is a graph illustrating variations in the diameter of an optical fiber over time, wherein the fiber is drawn using an apparatus not including a control tube according to the present invention; and

Figure 3 is a graph illustrating variations in the diameter of an optical fiber over time, wherein the fiber is drawn using an apparatus including a control tube according to an embodiment of the present invention.

Detailed Description of the Preferred Embodiments

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. In the figures, layers, components or regions may be exaggerated for clarity.

While the apparatus and methods of the preferred embodiments of the invention are described hereinbelow with reference to "upper" and "lower" orientations and relative positions and "upward" and "downward" directions, it will be appreciated that other orientations, relative positions and directions may be employed. As used herein, "upstream" and "downstream" refer to the direction of draw of the optical glass fiber and are not intended to indicate a vertical

orientation. However, the vertical orientation and arrangement as illustrated in **Figure 1** is preferred.

With reference to **Figure 1**, an optical fiber forming apparatus **100** according to embodiments of the present invention is shown therein. The apparatus **100** includes generally a draw furnace **110** and a diameter control assembly **150**. A glass preform **10** is supplied from an upstream or upper end **100A** of the assembly **100** and is heated by the draw furnace **110** such that an optical fiber **14A** is drawn therefrom in a downstream direction **P**. The optical fiber **14A** subsequently passes downstream through the diameter control assembly **150** and exits the apparatus **100** at a downstream or lower end **100B** thereof as an exiting fiber **14B**. Preferably, the diameter of the exiting fiber **14B** is the final diameter of the finished optical fiber, exclusive of any additional coatings or the like that are added further downstream in the process.

During the drawing procedure, a forming gas **G** is fed into the apparatus **100** at the upper end **100A**, passes downstream through the draw furnace **110** and the diameter control assembly **150**, and exits the apparatus **100** at the lower end **100B**. The diameter control assembly **150** serves to control the diameter of the fiber **14A** by protecting the fiber **14A** from turbulent flow of the forming gas **G** in the lower portion of the draw furnace **110**.

The preform **10** may be formed of high purity silica glass and/or doped silica glass, or other suitable material. The preform **10** may be formed such that either the core or the cladding (if present) of the drawn fiber **14A** is doped or such that both the core and the cladding of the drawn fiber are doped. The silica glass may be doped with germanium, fluorine, germanium and fluorine, boron, erbium, phosphorus or titanium. Other suitable dopants may be used as well. Methods and apparatus for forming the preform **10** are well known and will be understood by those of skill in the art from the description herein.

The draw furnace **110** includes a housing **111** having a lower flange **112** which may be water-cooled. An exit or lower opening **124** is defined in the lower flange **112**. A hollow exit cone **130** is positioned over the opening **124**. An annular susceptor tube **114** extends through the draw furnace **110** and defines an annular passage **120**. The susceptor tube **114** may be formed of, for example, graphite. Lower opening **124** and a side port **127** each fluidly communicate with the passage **120**. The preform is suspended in the passage **120** by handle **121**

which passes through the top plate **112**. An annular insulator (e.g., graphite) **116** and an induction coil **118** surround a portion of the susceptor tube **114**. The induction coil **118** is arranged and operable to heat a heating section **114A** of the susceptor tube **114**. Auxiliary passages **132** and **134** extend through the cone **130** and are fluidly connected to hoses **132A** and **134A**, respectively. A forming gas supply **18** (schematically illustrated) is provided to supply the forming gas **G** to the passage **120** under pressure of about 1.00 atm or slightly above. The draw furnace **110**, as described and illustrated above, is merely exemplary of suitable draw furnaces and those of ordinary skill in the art will appreciate the draw furnaces of other designs and constructions, for example, using other types of heating mechanisms, may be employed.

The diameter control assembly **150** includes an annular lower extended support tube **152**. The support tube **152** includes a tubular section **156** defining an interior passage extending therethrough. An upper flange **154** and a lower flange **158** extend radially from opposed ends of the tubular section **156**. The support tube **152** may be formed of steel or any other suitable material. The support tube **152** may also be water-cooled. The support tube **152** is secured to the lower flange **112** of the draw furnace **110** by bolts **155**. Other suitable fastening means may be used as well.

The diameter control assembly **150** further includes an annular control tube **160** having an upper end **160A** and a lower end **160B** and extending through the support tube **152** and into the passage **120**. Preferably, the control tube **160** is unitarily formed. The control tube **160** is preferably formed of quartz glass. Other suitable materials may be used; however, such materials will preferably have a melting point high enough such that the portion exposed in the furnace **110** does not melt or permanently deform when the apparatus **100** is operated.

The control tube **160** defines an interior passage **162**, which fluidly communicates with each of an upper opening **164** and a lower opening **166**. The diameter **D2** of the passage **162** (i.e., the inner diameter of the control tube **160**) is less than the corresponding diameter **D1** of the passage **120**. Preferably, the diameter **D2** varies by no more than 25 percent along the length of the passage, and more preferably is substantially uniform (i.e., varies by no more than 5 percent), from the end **160A** to the end **160B**. Preferably, the diameter **D2** is no greater than 100 mm, and more preferably, the diameter **D2** is between about 25 and 75 mm.

Preferably, the diameter **D2** is no greater than 70 percent of the diameter **D1**. More preferably, the diameter **D2** is between about 20 and 60 percent of the diameter **D1**.

An upper tube section **168** of the control tube **160** is disposed in the passage **120** and extends from the opening **124** (i.e., the lower end of the draw furnace **110**) to the upper end **160A**. The upper end **160A** is disposed a distance **L1** from the root tip **12** of the preform **10**. As used herein, the "root tip" is the farthest upstream portion of the preform/fiber combination where the fiber is within about 130 percent of its final diameter, exclusive of coatings and the like. The distance **L1** is preferably at least 100 mm, and more preferably, between about 200 and 400 mm. The outer surface of the upper tube section **168** and the adjacent, surrounding inner surface of the susceptor tube **114** define an annular, lower buffer cavity **123**. The length **L2** of the buffer cavity **123** is preferably at least 60 mm, and more preferably, between about 100 and 200 mm.

A lower tube section **169** extends from the opening **124** to the lower end **160B**. Preferably, the lower tube section **169** has a length **L3** (extending from the lower end of the buffer cavity **123** to the lower end **160B**) of at least 250 mm, and more preferably, of between about 495 and 1370 mm. The preferred length **L3** may depend on the fiber draw speed.

The outer diameter of the control tube **160** interfaces with the inner periphery of the cone **130** and/or the inner periphery of the lower flange **112** defining the opening **124** such that a fluid-tight seal is provided between the furnace **110** and the control tube **160** at or proximate the interface of the lower section **169** and the upper section **168** of the control tube **160**. A sealing member such as an O-ring or graphite gasket may be provided at the interface.

The outer diameter of the control tube **160** is preferably substantially the same as or slightly smaller than the inner diameter of the support tube **152** so that the control tube **160** may be frictionally retained in the support tube **152**. Additionally or alternatively, the control tube **160** may be retained in position by other means, such as a clamp and/or a support shelf. Spacers or an intermediate tube or sleeve may be provided between the support tube **152** and the control tube **160**.

Optionally, a door assembly **180** is secured to the lower flange **158** of the support tube **152** by fasteners or other suitable means. The door assembly **180** is

operable to adjust the width of a door opening **182**. The door assembly **180** may be pneumatically operated, for example, using an air supply hose **184**. Other types of door assemblies may be employed, suitable door assemblies being known to those of ordinary skill in the art. Preferably, the door assembly **180** is operable to adjust the size of the opening **182** to a smallest width of no more than 3 mm and to a largest width of at least 25 mm. In use, the door assembly **180** is operated to enlarge the opening **182** to a size sufficient to allow passage of a glass gob at initiation of the fiber draw, and the door assembly is thereafter operated to reduce the size of the opening **182** to a size sufficient to allow passage of the fiber **14A** but to reduce the potential for the flow of air up into the opening **166**.

The apparatus **100** may be used in the following manner to form the optical fiber **14B**. The preform **10** is inserted into the passage **120**. The induction coil **118** is operated such that the passage **120** is heated by the susceptor heating section **114A**. Preferably, the tip **12** of the preform **10** is heated to a temperature of between about 1800 and 2200 °C.

As the fiber **14A** is thus formed, the forming gas **G** is fed under pressure from the supply **18** through the side port **127**. The forming gas **G** flows down the passage **120** around the preform **10**, around the tip **12** and around the fiber **14A**. A portion of the forming gas **G** flows directly into the opening **164** of the control tube **160**. A remaining portion of the forming gas **G** may continue down the passage **120** around the outer surface of the control tube **160**, back up the passage **120**, into the buffer cavity **123** and ultimately through the opening **164**. After entering the opening **164**, the forming gas flows through the control tube **160** and the door assembly **180** and finally exits to the ambient atmosphere.

During the fiber forming process, substantially all of the flow of the forming gas **G** exits through the lower control tube opening **166**. Also, during the fiber forming process, substantially all of the forming gas is fed into the passage **120** and the passage **162** from a location upstream (i.e., above) the tip **12**. As used herein, "substantially all of the flow of the forming gas **G**" means at least about 95 percent of the forming gas **G** that is introduced into the passage **120**. A relatively small sample portion of the forming gas **G** may be intermittently or continuously withdrawn through the passage **132** and the hose **132A** to monitor the forming gas **G** (for example, to monitor the O_2 or carbon monoxide content of the forming gas **G**). During idle periods (i.e., when a fiber is not being drawn), an inert purging

gas, such as argon or helium gas, may be introduced into the passage **120** through the hose **134A** and the passage **134** to inhibit the entry of oxygen into the passage **120**.

During the process of forming the fiber as described above, the control tube **160** and buffer cavity **123** serves to isolate or protect the fiber **14A** from turbulent eddies and instabilities in the flow of the forming gas **G**. Such instabilities and turbulence may cause cooling rate transients that alter the local cooling characteristics and thereby cause inconsistencies in the diameter of the fiber along its length. That is, as the fiber **14A** tapers down to its ultimate diameter, the turbulence may cause differential cooling of different portions of the fiber and, as a result, different diameters. The turbulence may also exert mechanical forces on the fiber **14A** that generate variations in the fiber diameter. The buffer cavity **123** and the reduced diameter **D2** of the control tube **160** as compared to the diameter **D1** of the passage **120** serve to reduce the exposure of the fiber **14A** to forming gas turbulence. The buffer cavity **123** and the reduced diameter **D2** may also provide more uniform flow of the forming gas **G** through the control tube **160**. By providing more laminar forming gas flow, the control tube **160** and the buffer cavity **123** provide less variation in the diameter of the fiber **14A** along its length.

Preferably, the flow rate of the forming gas **G** is between about 10 and 150 slpm. More preferably, the flow rate of the gas **G** is between about 18 and 47 slpm.

The forming gas **G** may be any suitable forming gas. Suitable gases for the forming gas **G** include helium, argon, nitrogen and carbon monoxide or combination thereof.

In the upper tube section **168**, the fiber **14A** is preferably maintained at a temperature of between about 1900 and 1600 °C. In the lower tube section **169**, the fiber **14A** is preferably maintained at a temperature of between about 1700 and 1200 °C. At the point of exiting the opening **182**, the temperature of the fiber **14B** is preferably between about 1500 and 1000 °C. The ambient air temperature at the opening **182** is preferably about 20 °C. Preferably, the fiber **14A** is cooled at an average cooling rate of between about 3,000 and 15,000 °C/s in the lower tube section **169**.

According to further embodiments, the support tube **152** may be omitted. In this case, other suitable means may be provided for locating and supporting the

control tube **160**. The door assembly **180** may be omitted. A purge gas screen may be mounted adjacent the lower end of the control tube **160** to prevent or inhibit entry of ambient gases into the lower end of the control tube **160**.

EXAMPLE 1

An optical fiber was formed using an apparatus generally as described above except as follows. The apparatus did not include a diameter control assembly corresponding to the diameter control assembly **150**. A lower extended muffle (LEM) was mounted on the downstream end of the draw furnace. The LEM was generally configured and mounted in the same manner as the support tube **152**. The LEM had a length of about 17 inches (432 mm) and an inner diameter of about 2 inches (50 mm). The LEM was formed of stainless steel. The diameter of the furnace passage (i.e., the diameter corresponding to the diameter **D1**) was about 5 inches (127 mm).

Using the foregoing apparatus, the fiber was drawn at a draw speed of about 15 m/s, with a furnace temperature of about 1,880 °C and a helium forming gas provided at a flow rate of about 20 slpm.

Figure 2 is a graph representing the diameters of the fiber over time as measured by a fixed diameter sensor and correspond to the diameters of the fully drawn fiber along its length. The standard deviation in the diameters was 0.124254 μm.

EXAMPLE 2

A second optical fiber was formed using an apparatus corresponding to the apparatus **100** described above. The length **L1** was about 10 inches (254 mm), the length **L2** was about 7 inches (178 mm), and the length **L3** was about 20 inches (508 mm). The diameter **D1** was about 5 inches (127 mm) and the diameter **D2** was about 2 inches (50 mm). The fiber was drawn at a draw speed of about 15 m/s, with a furnace temperature of about 1,880 °C and a helium forming gas provided at a flow rate of about 20 slpm.

Figure 3 is a graph representing the diameters of the fiber over time as measured by a fixed diameter sensor and correspond to the diameters of the fully drawn fiber along its length. The standard deviation in the diameters was 0.027165

μm (<u>i.e.</u>, less than 22 percent of the standard deviation in the fiber diameters of **Example 1**).

Example 2 is merely exemplary of apparatus and methods according to embodiments of the present invention and the results that may be obtained therefrom and is not intended to limit the scope of the invention or the scope of the claims that follow.

The foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few exemplary embodiments of this invention have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the claims. Therefore, it is to be understood that the foregoing is illustrative of the present invention and is not to be construed as limited to the specific embodiments disclosed, and that modifications to the disclosed embodiments, as well as other embodiments, are intended to be included within the scope of the appended claims. The invention is defined by the following claims, with equivalents of the claims to be included therein.